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## A SKETCH OF THE GEOLOGY OF SOUTH AMERICA.

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IN preparing a sketch of the geology of South America I feel obliged to add some explanatory remarks. This sketch accompanies a map which forms a part of the second edition of the Physical Atlas of Berghaus (Gotha, Justus Perthes), which publication will be finished at the end of this year. Besides many other maps, the geological part of this atlas has sketch-maps of all continents, which represent the actual state of our knowledge. In preparing the sheet of South America I was aided by many geologists who, like myself, had occasion to explore some parts of this continent, especially by Orville Derby for the part of Brazil, by Luis Brackebusch for the part of the Argentine Republic, and by many others.

I thought it of some interest to the Association of North American Geologists to explain the main resemblances and differences which exist between the northern and the southern part of the great American continent, and to urge some remarkable points in the geological evolution of South America.

I pass by the primordial rocks, very imperfectly studied as yet in South America. The Paleozoic rocks are better known, and offer great interest. By the investigations of d'Orbigny, Forbes, Kayser, Rathbun, Clarke, Orville Derby, and those made recently by Dr. Ulrich, of Strassburg, upon the rich collection of

<sup>1</sup> Professor of Geology in the University of Freiburg i, B. Read before the Geological Society of America, August 25th, 1891.

fossils I brought home from the central plateau of Bolivia, the two following interesting points have been demonstrated :

1. That nearly all parts of the Paleozoic formations are represented in South America by marine deposits, being known by Cambrian, Lower and Upper Silurian, Devonian and Carboniferous fossils. As far as our knowledge extends, the older Paleozoic deposits—*i. e.*, the Cambrian and Silurian formations—are generally more disturbed and metamorphosed than the Devonian and Carboniferous series. In consequence of this fact, the faunas of the latter formations are better known than those of the former.

2. The richest Paleozoic fauna as yet known from South America is that of the Devonian formation. More than 150 different species have been described. The rich and well-preserved fauna collected by me in the eastern part of the Bolivian plateau has enabled Mr. Ulrich to show that the Bolivian deposits form a very important link between those of North America on one side, and those of Brazil, the Falkland Islands, and South Africa on the other side. The highly fossiliferous clay slates, sandy clays, and sandstones widely distributed in Bolivia and Brazil are the equivalents of the Oriskany sandstone, the Upper Helderberg, and the Hamilton groups of North America. Their fauna bears an American, not a European, character, as proved by the two commonest and most characteristic Brachiopods :

1. *Leptocælia flabellites*. This fossil has been found in North America, Bolivia, on the Falkland Islands, and in South Africa.

2. *Vitalina pustulosa* is known from North America, Brazil, Bolivia, and South Africa.

Partly by the identity, partly by the similarity of the Devonian faunas of the named regions, it appears quite evident that a great Devonian sea embraced large parts of both Americas and South Africa.

The Carboniferous deposits seem to be much more restricted in South America than the Devonian. The sub-Carboniferous is mostly composed of non-fossiliferous sandstones ; the Upper Carboniferous, containing representatives of universally distributed Brachiopods and Gastropods, and of the genus *Fusulina*, is known from Peru, Bolivia, and some parts of Brazil.

During the Permian, Triassic, and Jurassic epochs the greatest part of the South American continent, in the same manner as the North American, was above the sea-level, for according to the researches made by Brackebusch in the Argentine Republic, by myself in Bolivia, and by Derby in the Matto-Grosso region, a great if not the greatest, part of the red sandstones generally considered to be of Permian or Triassic age seems to belong to the Cretaceous formations,—probably to the lower part of it. The flora which existed during the Permian and Triassic periods upon the South American continent is of high interest. The coal-bearing deposits of South Brazil and those of the Argentine and Chilian Cordilleras contain many representatives of the so-called “Glossopteris flora” known from South India, Australia, and South Africa. The age of these coal deposits is not everywhere the same. The flora of South Brazil has been referred to the younger Paleozoic, because it contains some Paleozoic types of plants; those of the Argentine and Chilian Cordilleras belong to the Rhætic group, and are partly covered conformably by marine deposits of the Lower Lias.

Marine deposits of the Triassic and Jurassic formations have only been found in the western part of the continent,—namely, in the Cordillera between the  $5^{\circ}$  and  $35^{\circ}$  of southern latitude. The Triassic fossils are of the same type as those found in California and Western Canada, the leading fossil being a species of *Pseudomonotis* of the group of *Ps. semicircularis* Gatt. From the Jurassic formation nearly all horizons have been found in a fossiliferous state, and the rich collections made in different parts of the Argentine, Chilian, and Peruvian Cordilleras have enabled us to determine that the succession of marine organic life during this period was quite the same on the Pacific slope as in Europe and East India, and there have existed very intimate faunistic relations between these regions. As regards the extension of marine deposits of the Triassic and Jurassic epochs, there exists a remarkable similiarity between North and South America, being themselves confined to a small strip parallel to the Pacific coast.

In contrast to this small extension of marine Triassic and Jurassic rocks, the Cretaceous deposits cover a very large area in South America. Marine Cretaceous fossils are found in nearly all parts of the Cordillera from South Patagonia to East Venezuela, and Mr. White has discovered a rich fauna of the Cretaceous formation of East Brazil. The invasion of continental areas by the sea at the earlier Cretaceous period, which has been observed in many parts of Central Europe, seems to have taken place on a much larger scale in both Americas. We know now, by the investigations of Hill and White, that a part of the Cretaceous strata of Texas formerly regarded as Upper Cretaceous belongs to the lower part of this formation. The Cretaceous formation of Mexico appears as a direct continuation of the Texas deposits; and as far as our present knowledge extends, the relations between the faunas of the older Cretaceous of these regions and those of Venezuela, Colombia, and North Peru are very intimate. It is interesting to see certain characteristic fossils of the Lower Cretaceous of the north reappear in the south. The famous genus *Aucella*, widely distributed on the slopes of the North Pacific, has been recently mentioned by N. Ritin from Mexico; by White from Brazil; I know it also from the environs of Lima associated with *Ammonites* of the Neocomian of Europe. The Cretaceous sea which covered the central part of America probably continued farther to the east. We find, therefore, some remarkable relations between the Lower and Upper Cretaceous faunas of South America, especially of Colombia and Peru, and those of North and West Africa. Some forms of *Buthiaceras* known from Algiers are found abundantly in the Upper Amazonian region. The truly marine deposits of the central part of America disappear to the north and the south, and seem to be replaced by sandy deposits without marine fossils. Probably a great part of the red sandstone formations which occur in Brazil, Venezuela, Bolivia, and in the north of the Argentine Republic, take the same place relative to the marine sediments of the older Cretaceous as do the *Atlantosaurus* beds, the Trinity and Tuscaloosa formations in the north,—namely, underlying themselves or forming an equivalent of them.

I cannot conclude my remarks upon the Mesozoic formations of South America without mentioning the two following peculiarities. The first is the fact that, wholly independent of the marine Cretaceous deposits of the Cordillera on the Pacific coast of South Chili, glauconitic sandstones are found which contain a rich fauna of the uppermost Cretaceous, especially on the Island of Ouiriquina. Besides many Ammonites and Baculites, partly identical with those from South India, this fauna is characterized by the abundance of Gastropods of a Tertiary type. The Cretaceous beds are covered conformably by a lignitic formation, whose fauna does not contain the Cretaceous fossils; but stratigraphically both formations are intimately united. So a curious parallelism seems to exist in these deposits of South Chili, with the Chico-Tejon group of North California.

The second point to be pointed out is the abundance of eruptive rocks within the Triassic, Jurassic, and Cretaceous formations of the Cordillera. On the western side of the border of Chili and Peru, where the marine deposits of these formations predominate, only a very small part of the rocks are formed by limestones, clay slates, or sandstones. These appear, however, to be interlaid between stratified masses of porphyritic, melaphyric, and andesitic material, the entire thickness of which strata reaches several 1000 meters. So far as we know, this is the largest area of eruptive formation of Mesozoic time. The Cordillera of South America is famous for its eruptive formations of the latest time, but it merits no smaller attention for its submarine eruptions during the Mesozoic time, and for the injection of the Mesozoic strata by truly granitic and dioritic rocks.

The Tertiary formations, well developed in the Argentine Republic, have been subdivided into a number of groups by Doring. According to the researches of Ameghino, the younger Tertiary deposits of South America show a remarkable peculiarity. This paleontologist discovered the remains of human beings not only in the Pliocene, but also in the Miocene, deposits. I must confess that, comparing the European Mesozoic strata with those of South America, quite another classification of the latter seems to be indicated. What has been called the Pampean formation in the Argen-

tine Republic, and referred to the Pliocene, is no other than the Loess in Europe, whose formation took place between the two latest glaciations. Adopting this view of the case, the so-called Miocene strata probably belong to the great ice period, and the Pehuelche stratum represents only the morainic deposits of the last ice period. The Plistocene deposits of South America are not yet studied in detail, but the glacial deposits I met in South Patagonia can be easily distinguished into two different groups: those of a former more extended and overarched formation, covering not only the lower parts, but also the table mountains of over 100 m. in height; and the younger formation, the kettle moraines of which are found along the foot of the Cordillera. The extension of true glacial deposits within the Cordillera seems to be much greater than generally admitted. Twenty years ago Raimondi described clearly true moraines from the Cordillera Nev. of Ancachs (about  $9^{\circ}$  s. lat.), reaching down to 2500 m. above the sea-level. I myself found moraine deposits in the Cordillera of Copiapo ( $28^{\circ}$  s. lat.), about 1200 m. above the sea-level, and these observations coincide quite well with those made north of the equator by Sievers, who found the traces of former glaciation in the Sierra Nevada do Santa Marka and in the Sierra Nevada do Tarija. These facts seem to prove that the glacial periods did not alternate on both hemispheres, but that they were contemporaneous. In this respect further studies upon the Plistocene formations of the Cordillera of South America will be of great scientific value.

Besides the true glacial deposits and the æolean formation of Loess and loam, there exist in South America, especially on the High Plateau of Bolivia, like deposits of great extent. Terraces and tufa deposits analogous to those of the Great Basin of the West indicate a formerly much wider extension of the Lake Titicaca over the whole High Plateau from Southern Peru to the Argentine frontier. It seems that this former extension of lakes in South America coincides also with that of the lakes of the Great Basin region.